

Crossing the Duality:

the turbulence and statistics of gravity

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Outline

- Fluid-gravity duality
- Holography \rightarrow astrophysics
- An example
- Current efforts

Fluid-gravity duality

$$ds^2 = -2u_\mu dx^\mu dr + r^2 \left(\eta_{\mu\nu} + \frac{1}{(br)^3} u_\mu u_\nu \right) dx^\mu dx^\nu \quad (1)$$

$$T_{\mu\nu} \sim (3u_\mu u_\nu + \eta_{\mu\nu}) + \text{viscous terms} \quad (2)$$

Must obey $\partial_\mu T^{\mu\nu} = 0$.

Fluid-gravity duality

Regime of validity: $LT \gg 1$

(for black hole-AdS: large boundary, large black hole)



turbulent regime ($Re \gg 1$) on fluid side

Holography \rightarrow astrophysics

- I Take a result from non-relativistic turbulence
- II Generalize to relativistic, conformal fluids
- III Get bulk analog of result
- IV Divorce result from dual language
- V Seek similar result for asymptotically flat

An example

I Take a result from non-relativistic turbulence

- 2+1 dimensional inverse cascade

“Inertial Ranges in Two-Dimensional Turbulence”

Kraichnan, Robert H., Physics of Fluids, 10, 1417-1423 (1967)



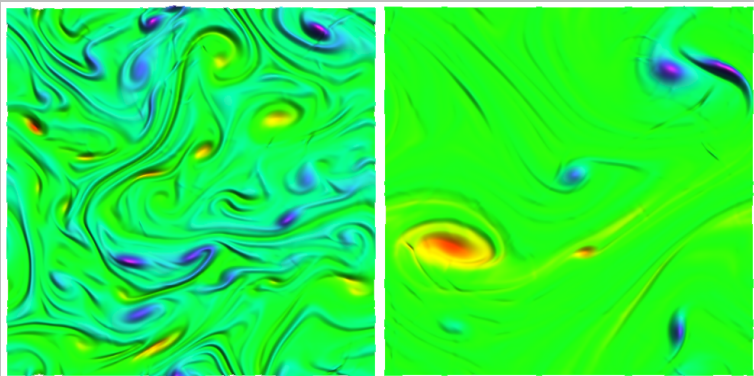
An example

II Generalize to relativistic, conformal fluids

- Still occurs when $P = \rho/2$, subsonic regime

“Turbulent flows for relativistic conformal fluids in 2+1 dimensions”

F. Carrasco, L. Lehner, R. C. Myers, O. Reula and A. Singh, Phys. Rev. D
86 (2012) 126006



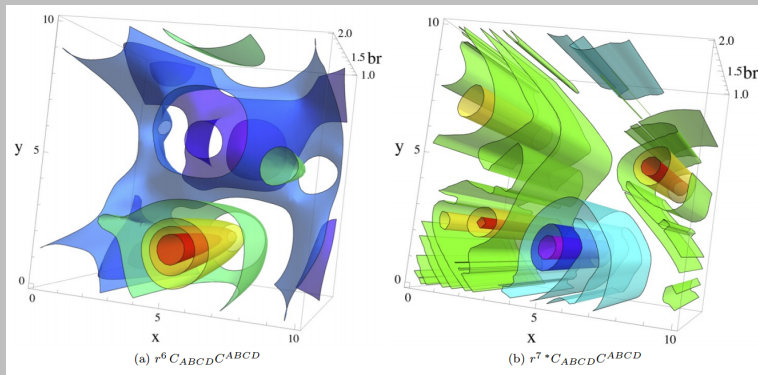
An example

III Get bulk analog of result

- Transfer of energy among QNMs towards larger length scales

“Holographic Path to the Turbulent Side of Gravity”

S. R. Green, F. Carrasco, and L. Lehner, Phys. Rev. X4 (2014), no. 1
011001



IV Divorce result from dual language

- $\text{Re}_g \sim T_{\text{Hawking}} \|h_{AB} (\partial/\partial r)^B\| L$ must be large
- QNMs must be long-lived

“Holographic Path to the Turbulent Side of Gravity”

S. R. Green, F. Carrasco, and L. Lehner, Phys. Rev. X4 (2014), no. 1
011001

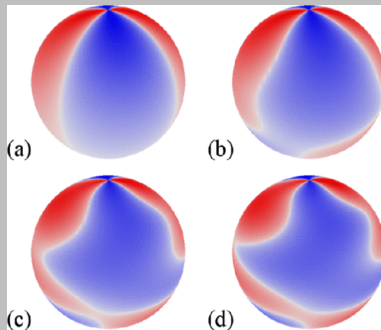
An example

V Seek similar result for asymptotically flat

- Parametric instability of QNMs for rapidly-spinning BHs
- Transfer of energy to smaller m , ω

“Turbulent Black Holes”

H. Yang, A. Zimmerman and L. Lehner, Phys. Rev. Lett. 114 (2015)



One current effort

I Take a result from non-relativistic turbulence

- 2+1 dimensional scaling relations

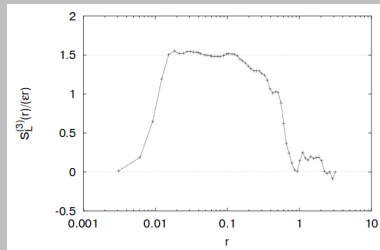
“Three-point velocity correlation functions in two-dimensional forced turbulence”

Bernard D 1999 Phys. Rev. E 69 6184

$$\left\langle [(\mathbf{v}(\mathbf{r}) - \mathbf{v}(0)) \cdot \hat{\mathbf{r}}]^3 \right\rangle = \frac{3}{2} \epsilon r \quad (3)$$

“Inverse cascade in two-dimensional turbulence: deviations from Gaussianity”

Boffetta, G., A. Celani, and M. Vergassola, 2000, Phys. Rev. E 61, R29.



One current effort

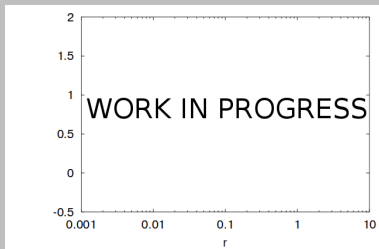
II Generalize to relativistic, conformal fluids

- 2+1 dimensional *relativistic* scaling relations

“Scaling relations in two-dimensional relativistic hydrodynamic turbulence”

JRWS, L. Lehner, Y. Oz, J. High Energ. Phys. (2015) 2015: 67.

$$\langle T_{0i}(\mathbf{r}) T_r^i(0) \rangle = \frac{1}{2} \epsilon r \quad (4)$$



One current effort

III Get bulk analog of result

- WORK IN PROGRESS

IV Divorce result from dual language

- WORK IN PROGRESS

V Seek similar result for asymptotically flat

- WORK IN PROGRESS

Stay tuned...

The end

Thanks for listening.